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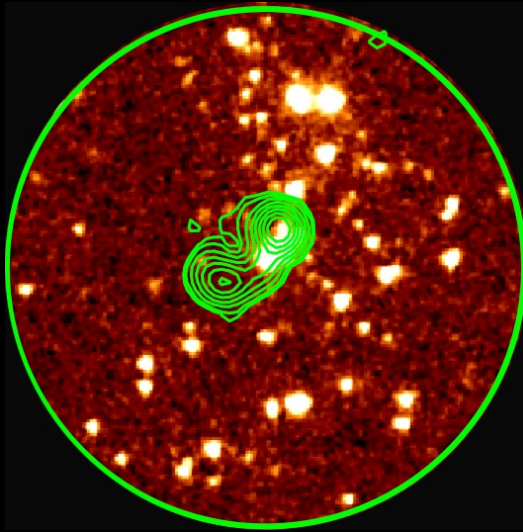
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Where the Wild Things Are: Galaxy Evolution and Radio Source Properties in the High- z COBRA Survey



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Galaxy Cluster Formation 2021 – June 18, 2021

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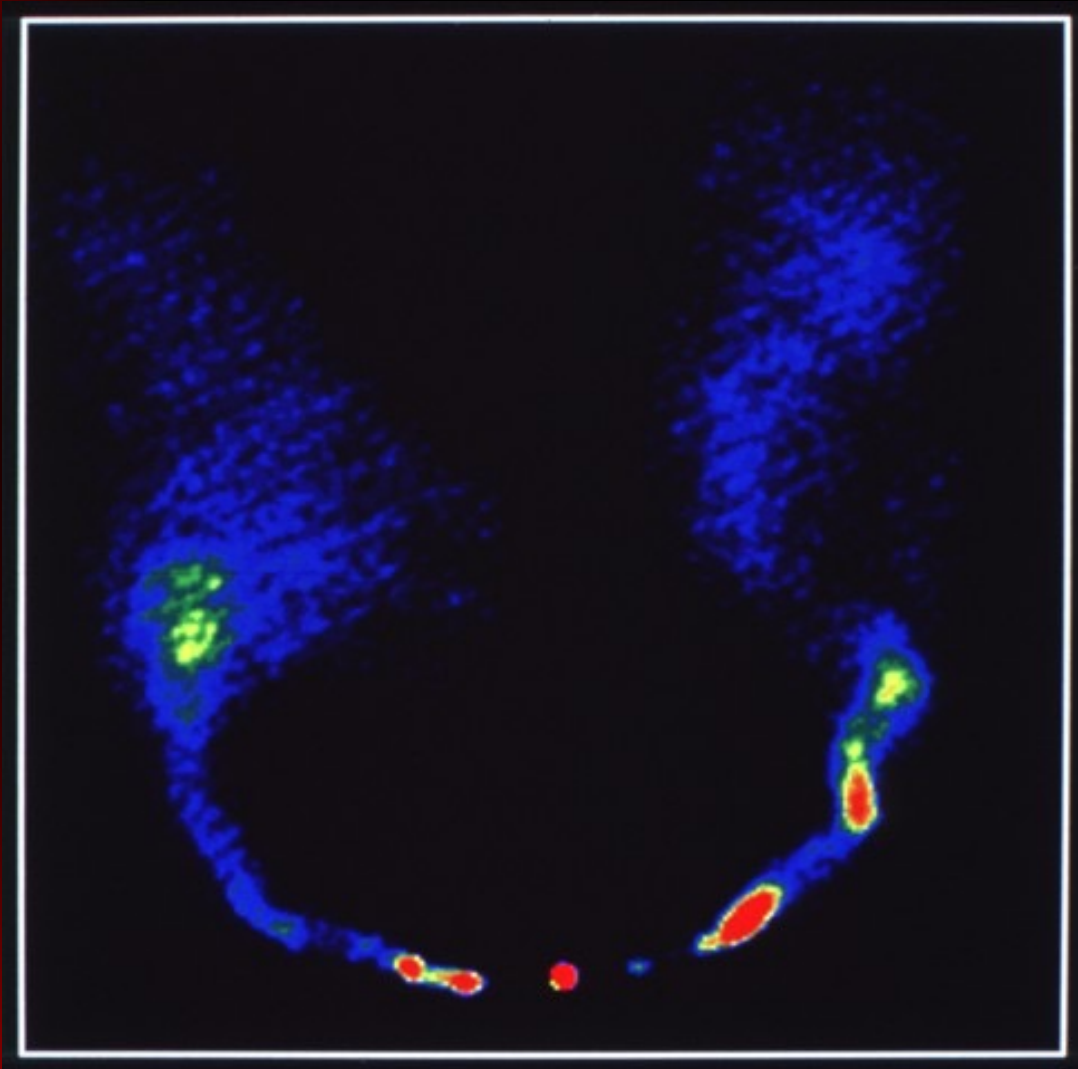
The High- z Clusters Occupied by Bent Radio AGN (COBRA) Survey



- Sample of 646 bent, double-lobed radio sources selected from the VLA FIRST survey (Paterno-Mahler et al. 2017)
 - $0.3 < z < 3.0$
- 41 spectroscopically confirmed quasars
- Observations: Optical (Lowell Discovery Telescope – 4.3m), IR (Spitzer)

Waveband	Number of fields
3.6 μ m	646
4.5 μ m	135
<i>i</i> -band	90
<i>r</i> -band	38

Bent, Double-Lobed Radio Sources

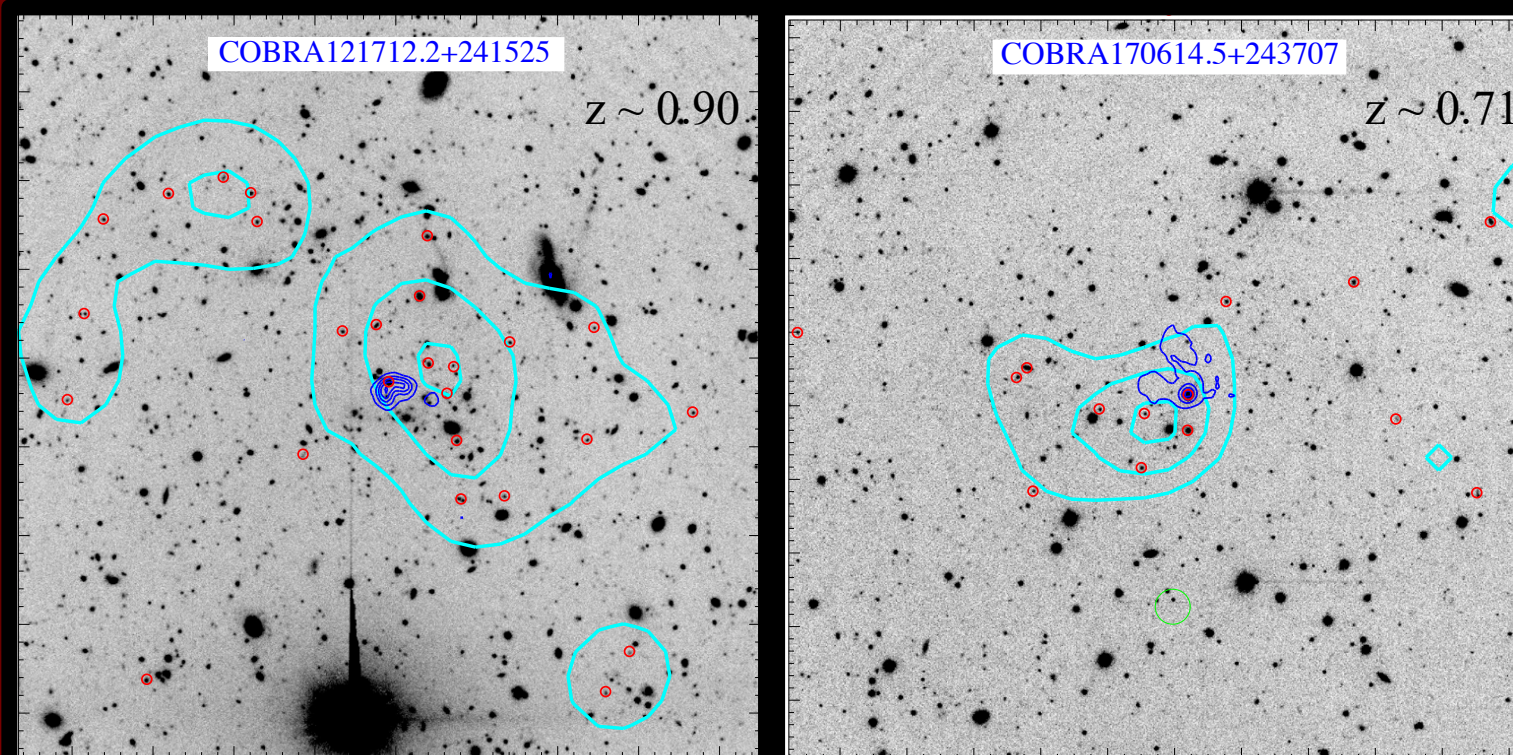


- The unique “C” shape of bent radio sources is caused by ram pressure acting on the radio lobes
 - Most commonly, this pressure is caused by the relative motion between the galaxy and the ICM (e.g., Owen & Rudnick 1976)
- At low redshift, bent sources are commonly in galaxy clusters (e.g., Blanton et al. 2000, Wing & Blanton et al. 2011, Garon et al. 2019)

Question 1

Are high- z bent, double-lobed radio sources found in galaxy clusters characterized by strong red sequences?

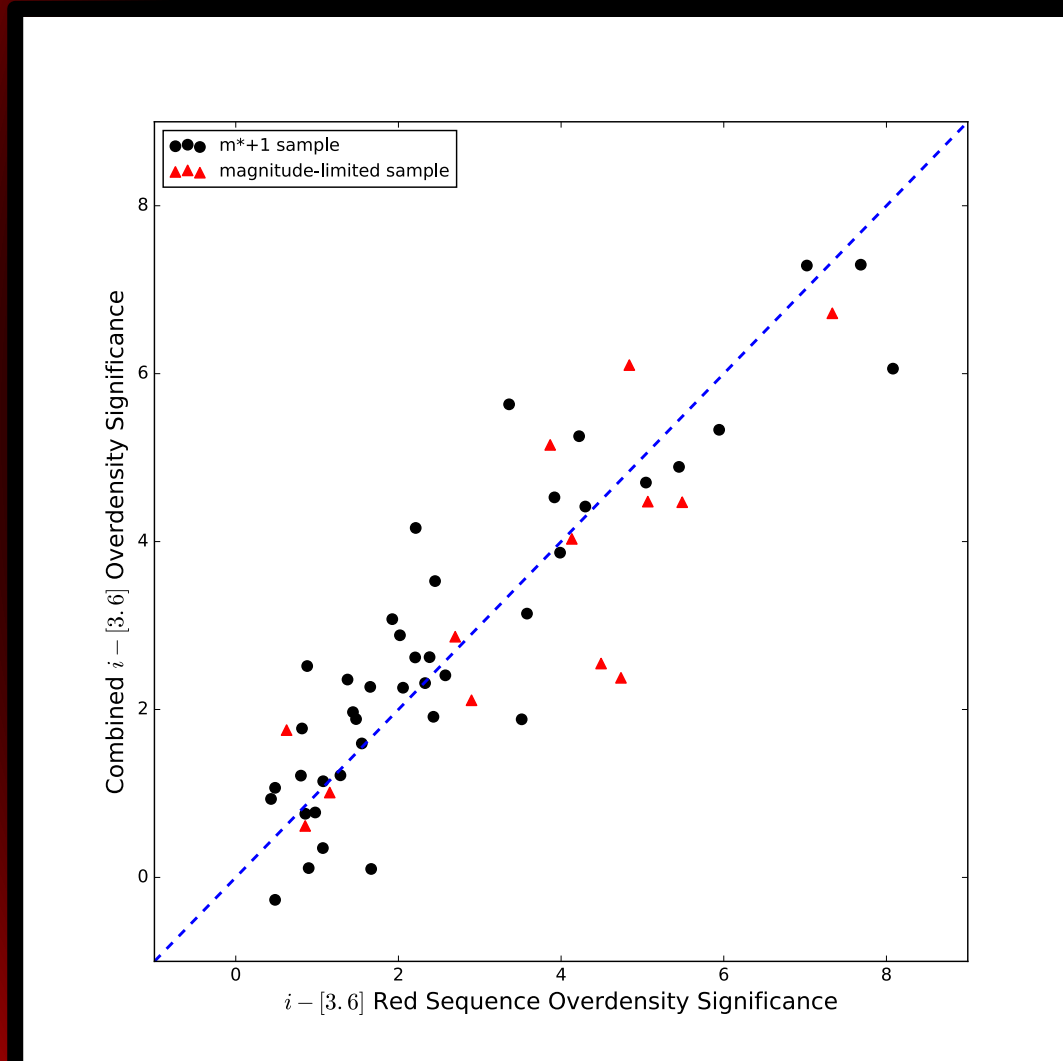
The Search for Red Sequence Galaxies



Golden-Marx et al. 2019, 2021

- Estimate the red sequence color based on the host galaxy ± 0.15 (red circles) (e.g., Blakeslee et al. 2003; Mei et al. 2006, 2009; Snyder et al. 2012; Lemaux et al. 2012; Cerulo et al. 2016)
- Search the combined Spitzer/LDT fov for all red sequence galaxies to best identify the peak surface density of red galaxies
- Define cluster candidates as a 2σ overdensity in a $1'$ region relative to the background

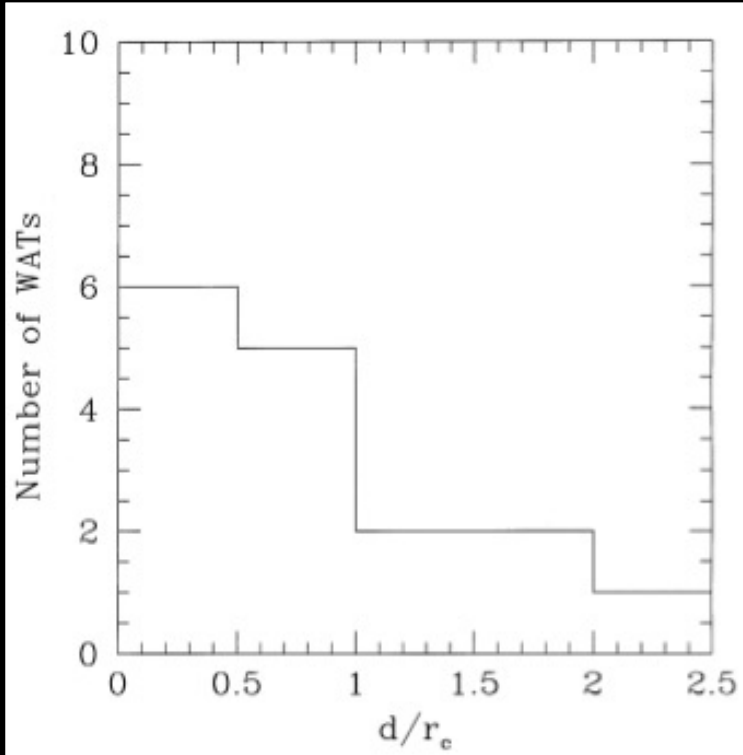
Further Verification – The Combined Overdensity



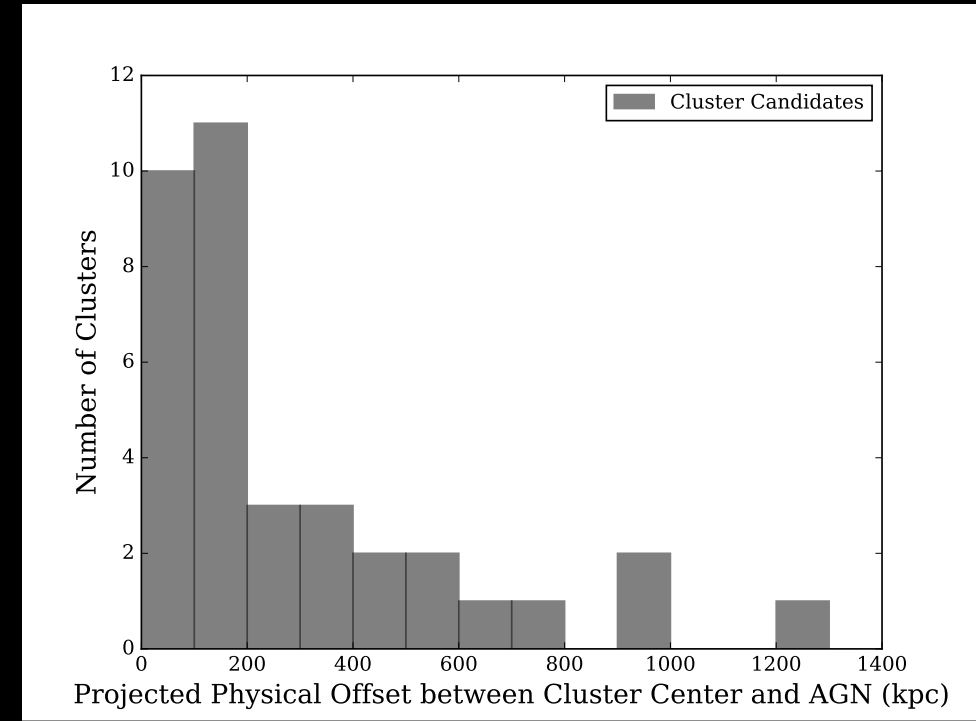
- Weight the likelihood of each galaxy (red sequence, redder, and bluer) being a cluster member at our redshift estimate
 - Using spectroscopic and photometric redshifts and optical/IR imaging from the ORELSE survey (Lubin et al. 2009)
- Identify 39 high- z cluster candidates at $0.35 < z < 2.2$

The Location of Bent Sources in COBRA Clusters

- Sakelliou & Merrifield (2000) found that the 11 of 16 of their low- z bent sources are within 300kpc (1 cluster core radius) of the cluster center
- Similarly, Golden-Marx et al. (2021) found 24 of 39 are within 300kpc of the cluster center

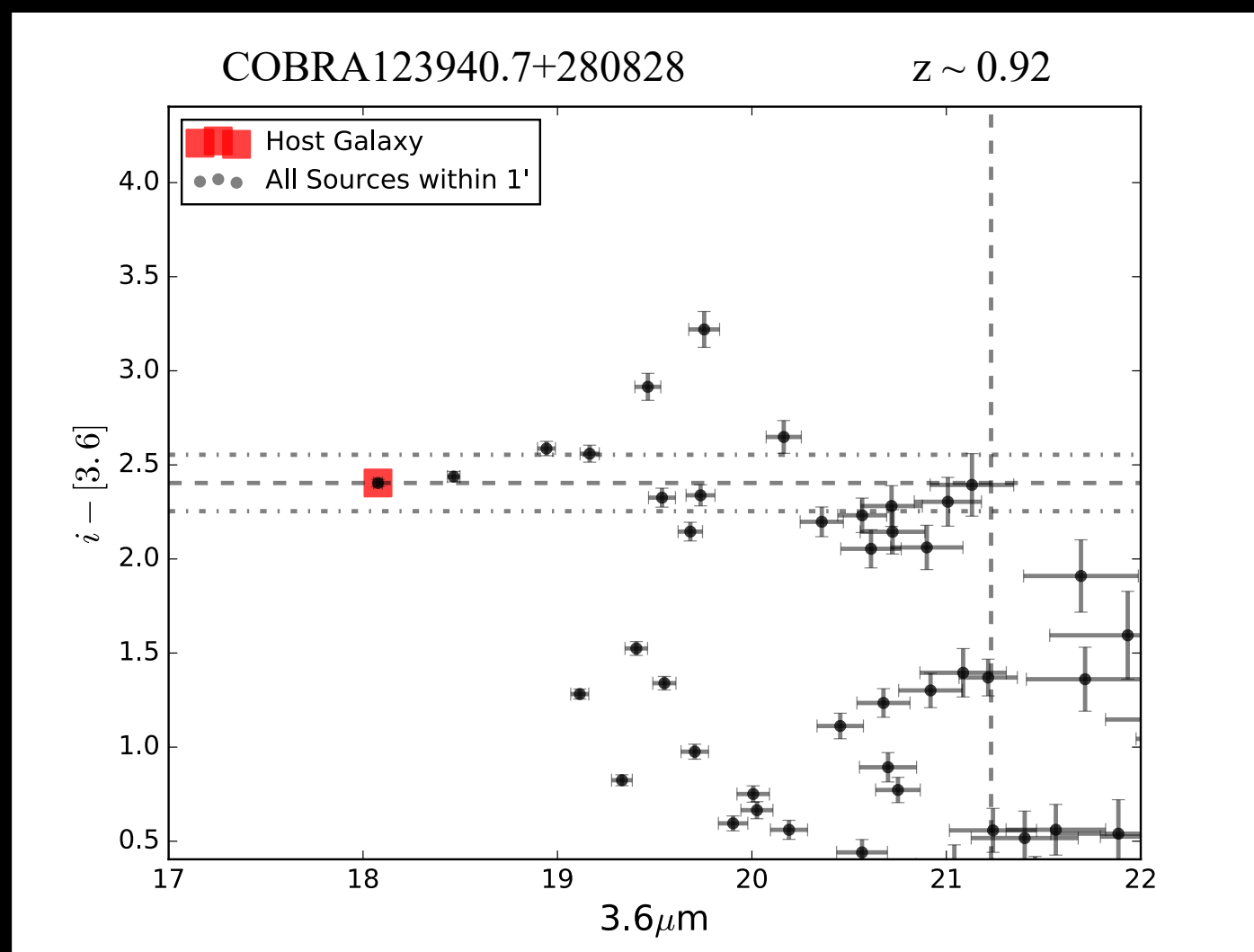


Sakelliou & Merrifield 2000



Golden-Marx et al. 2021

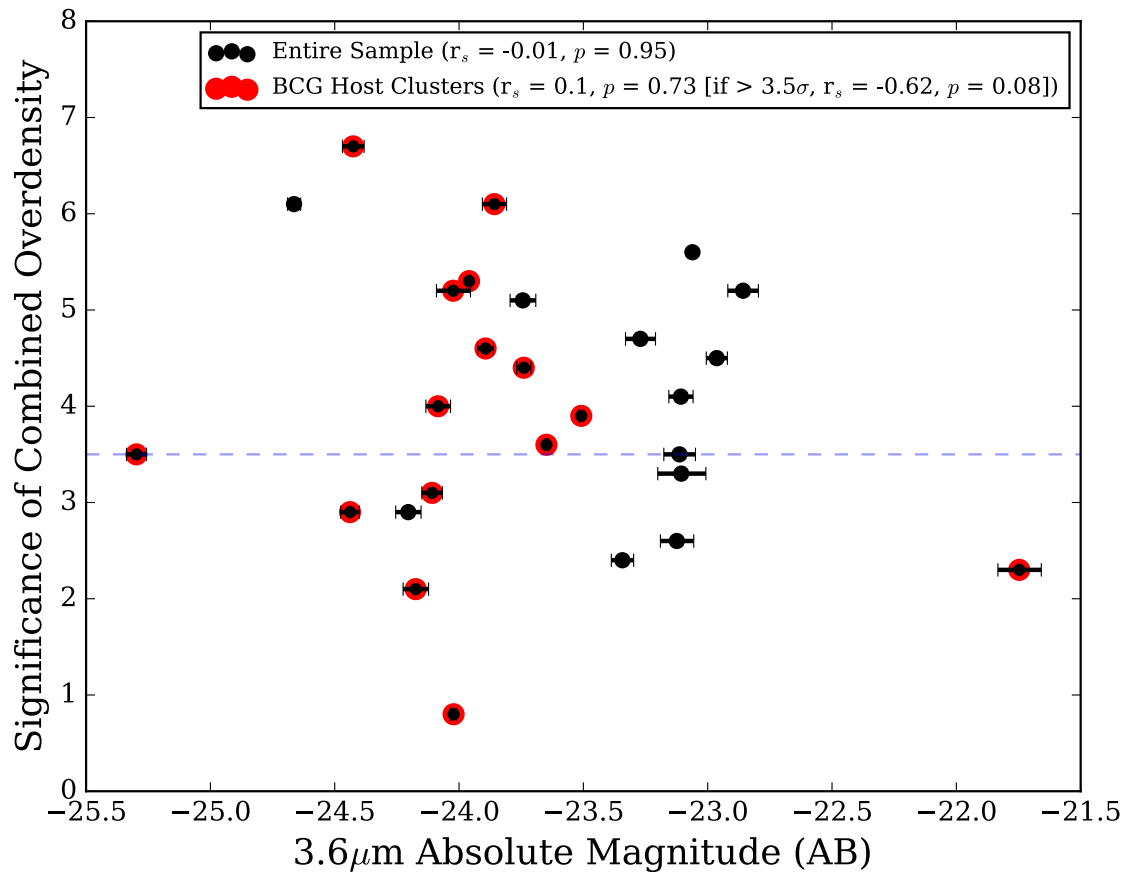
Are Bent Radio Source Host Galaxies Proto-BCGs?



Golden-Marx et al. 2019

- Identify the BCG as the brightest red sequence galaxy (exclude quasars)
- 55% of our radio hosts are BCGs (Golden-Marx et al. 2021)

Do COBRA proto-BCGs trace the overall cluster richness?

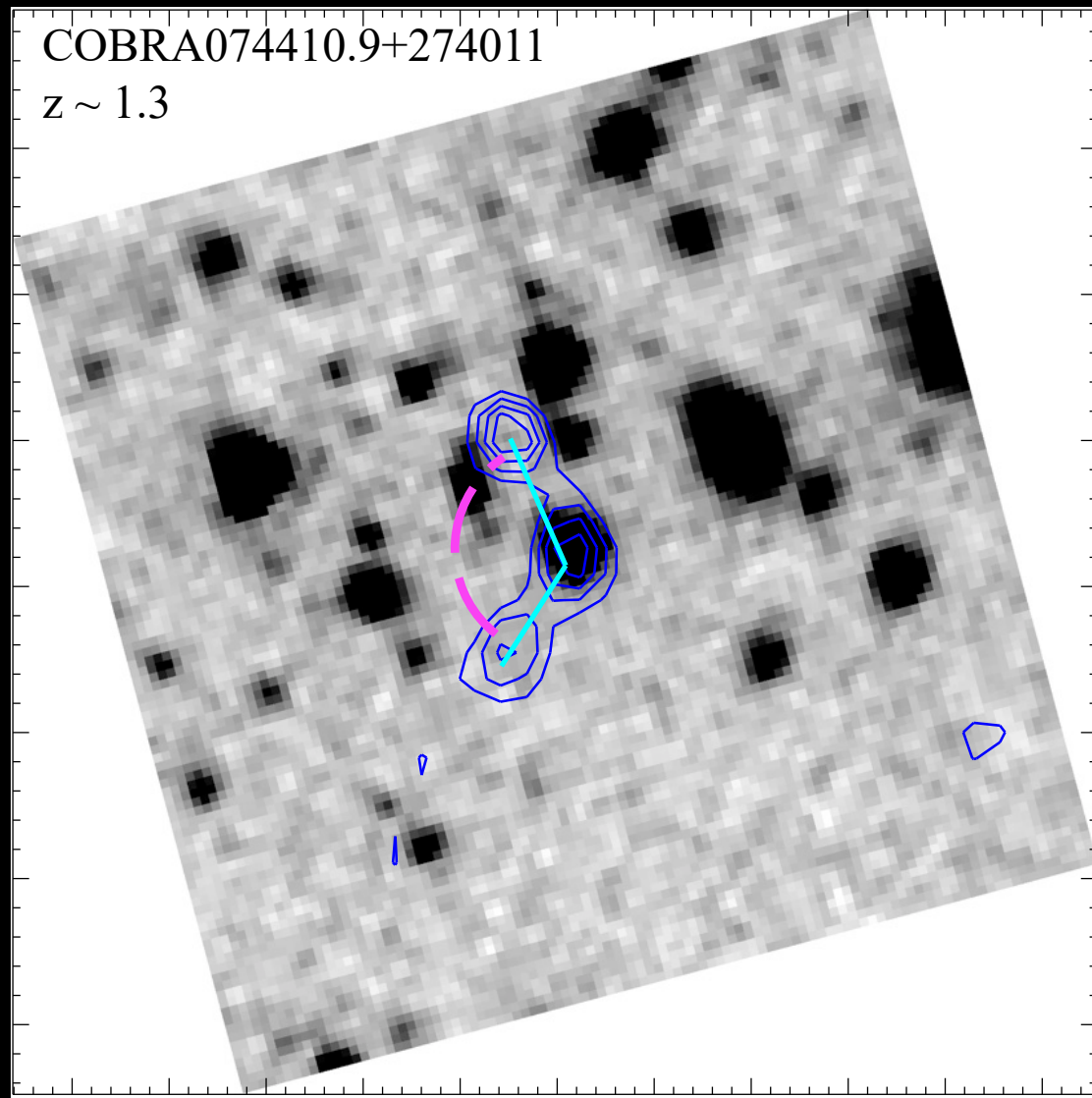


- Among the richest COBRA clusters ($> 3.5\sigma$), we find a strong correlation between the absolute magnitude of the BCG and the combined overdensity
 - Could hint at the possibility of these systems being further along their evolutionary paths (e.g., Lin & Mohr 2004, Wechsler & Tinker 2018)

Question 2

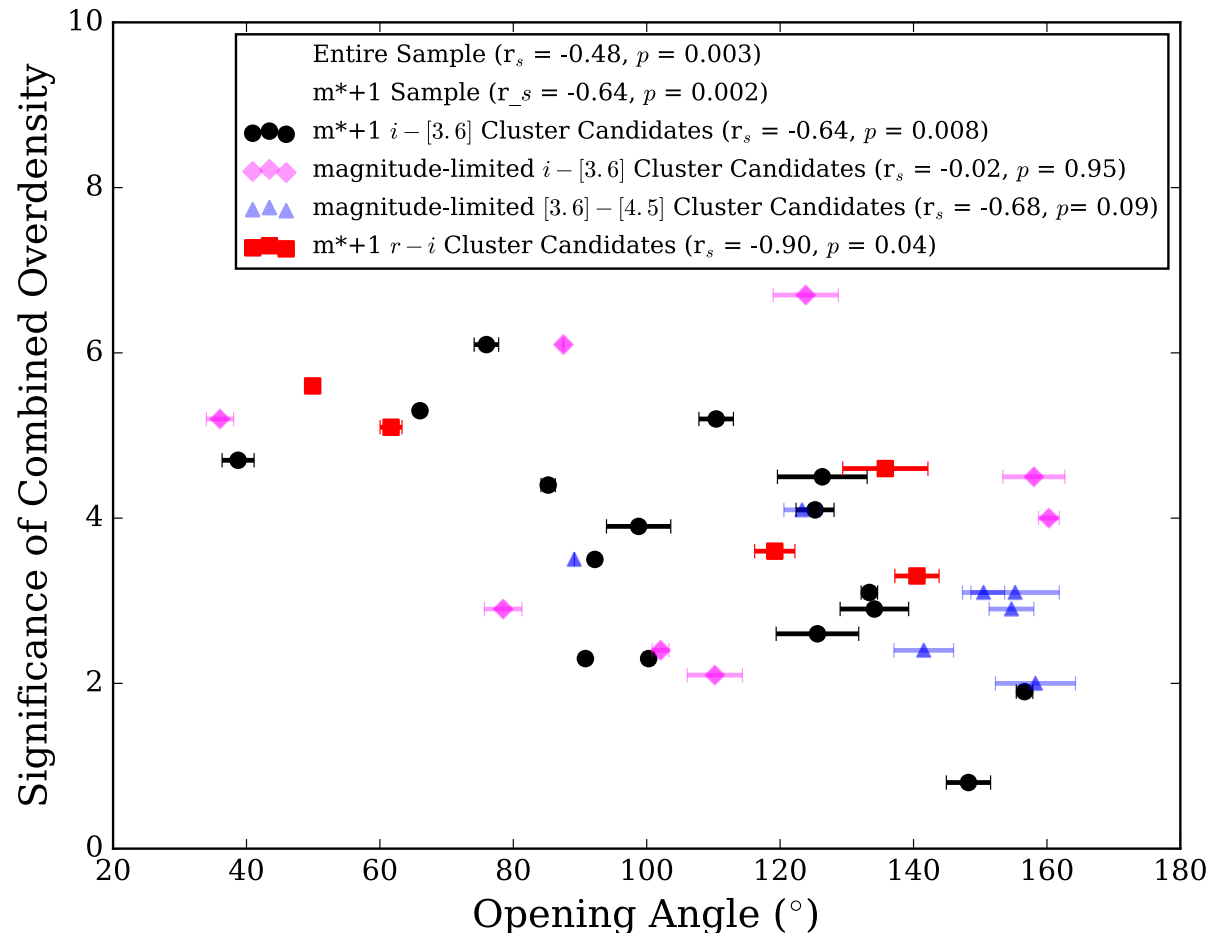
What are the radio properties of the bent radio sources and are they linked to environment?

Measuring the Opening Angle



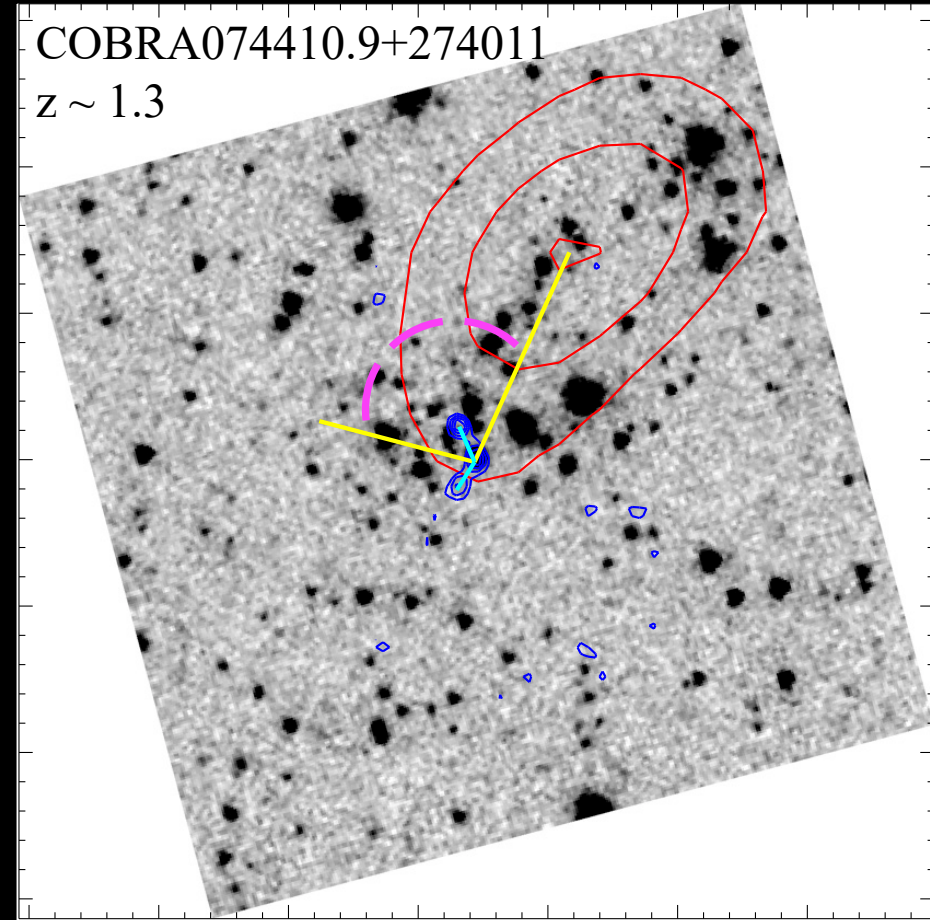
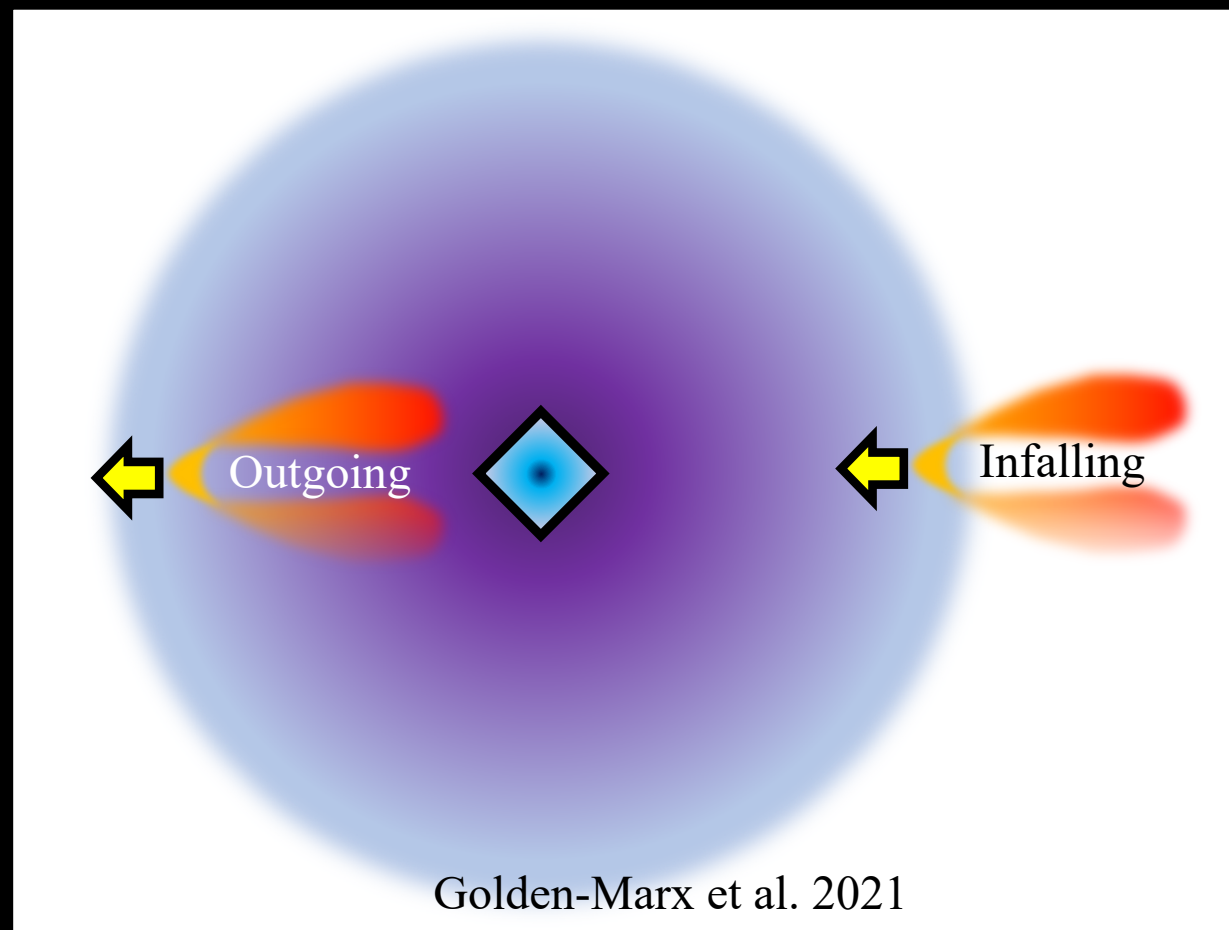
- Measure the opening angle based on the detected radio components in the VLA FIRST catalog
- 75% are WATs ($> 90^\circ$)

Does the Opening Angle Correlate with Environment?



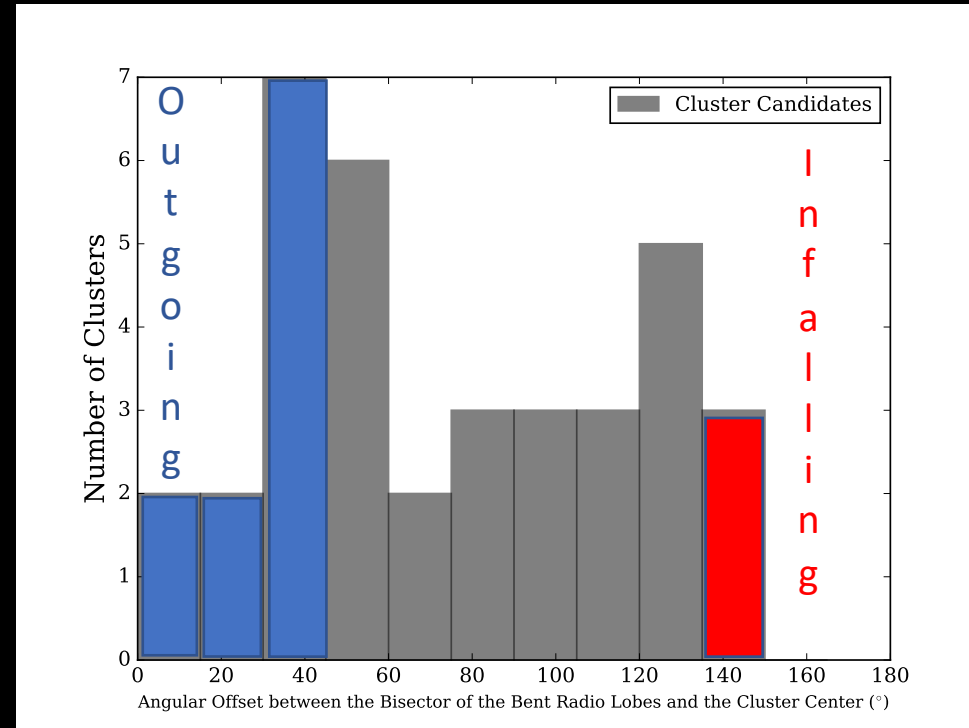
- Find a negative correlation between the size of the opening angle and cluster richness
- If richer clusters have a denser ICM, this may imply the ICM density is the dominant driver of the bent morphology (not infall velocity); (e.g., Hardcastle et al. 2005, Morsony et al. 2013)

Where is the Bent Radio Source?



- Sakelliou & Merrifield (2000) found that the overwhelming majority of their low- z bent sources are infalling

Have bent AGNs passed through the cluster center?



Golden-Marx et al. 2021

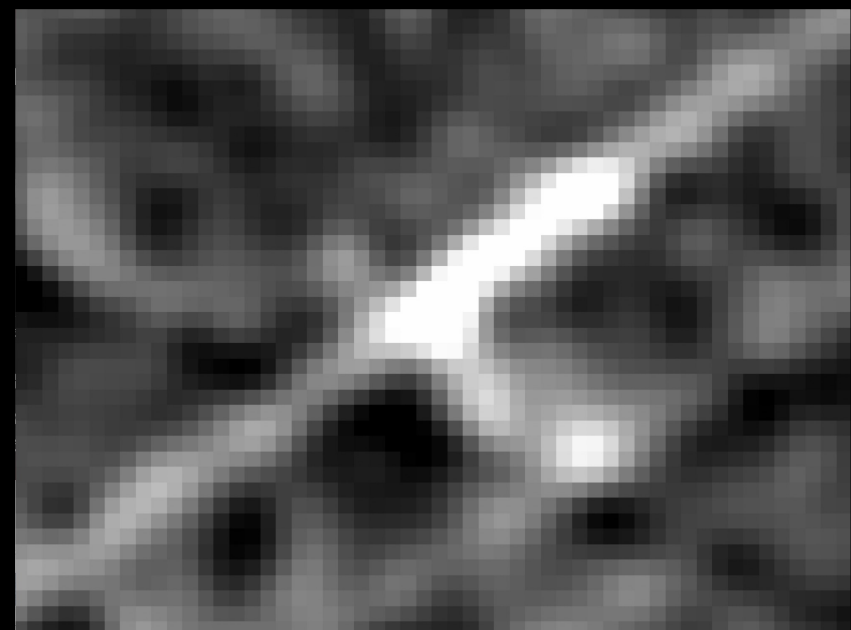
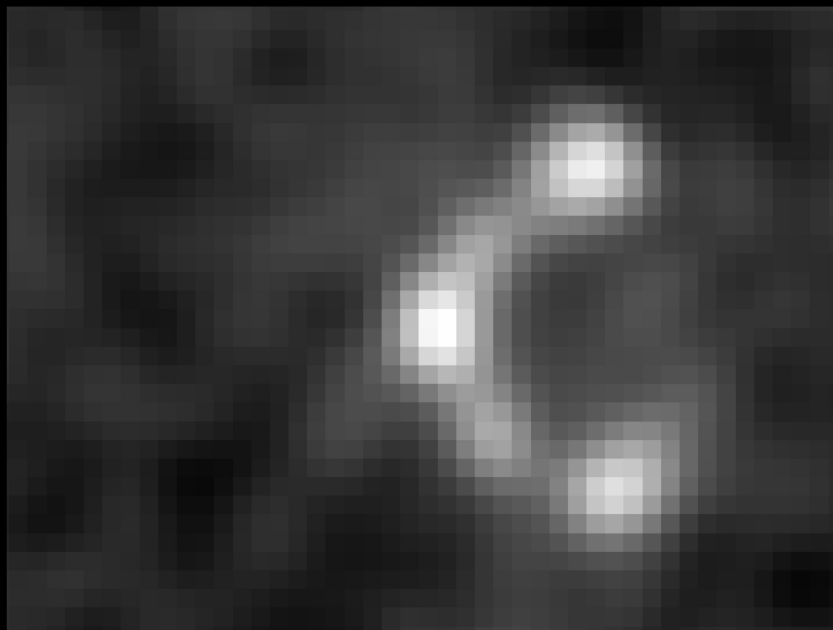
- 11 sources are outgoing, 3 are infalling, and 22 are intermediate
 - The farthest sources from the cluster center are infalling or intermediate
- This might imply that high- z bent sources don't follow radial paths or the ICM is not dense enough to thoroughly disrupt the radio lobes

Additional Radio Observations

LOFAR (0.143GHz)

VLA FIRST (1.44GHz)

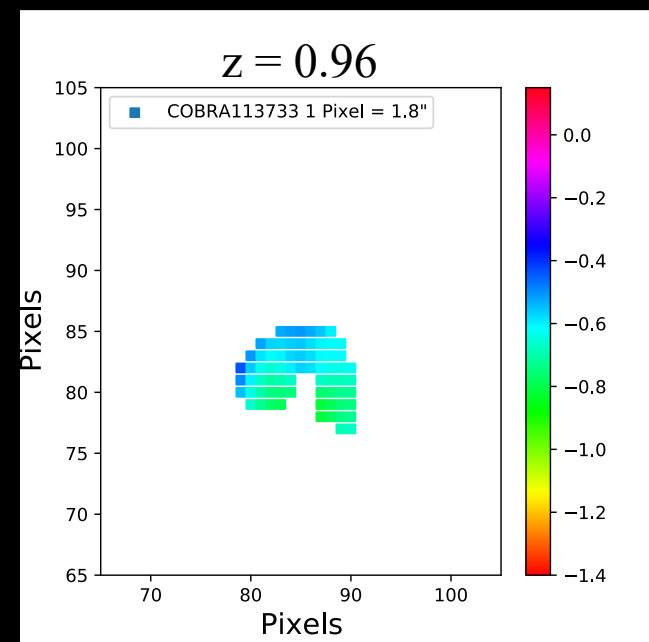
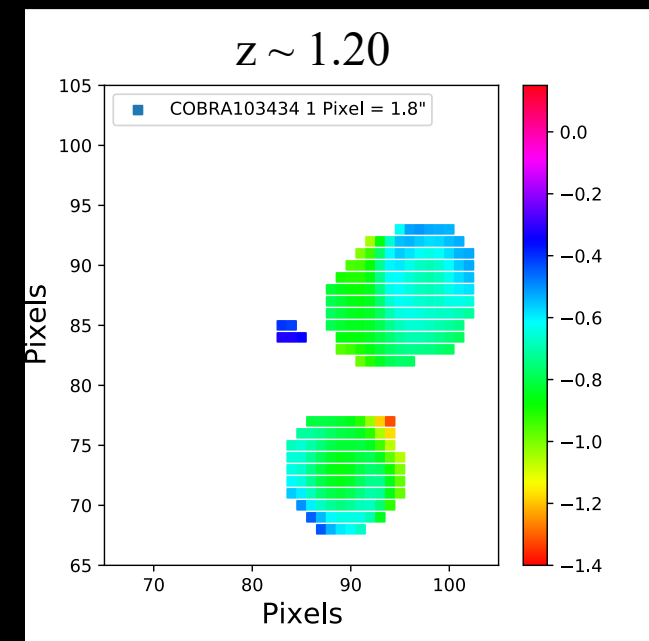
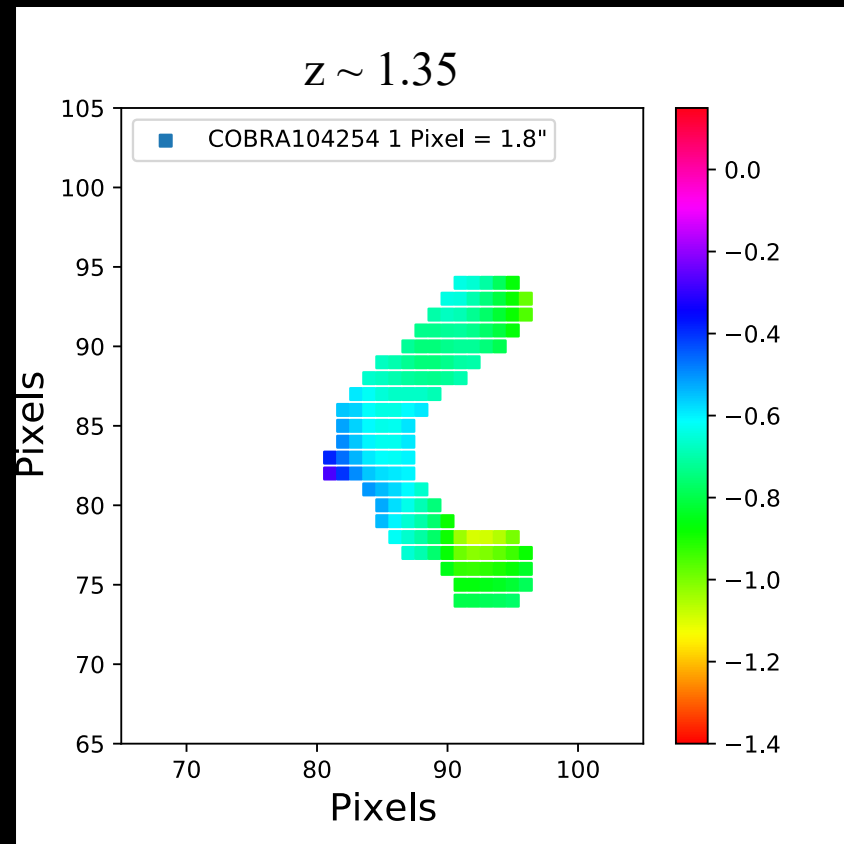
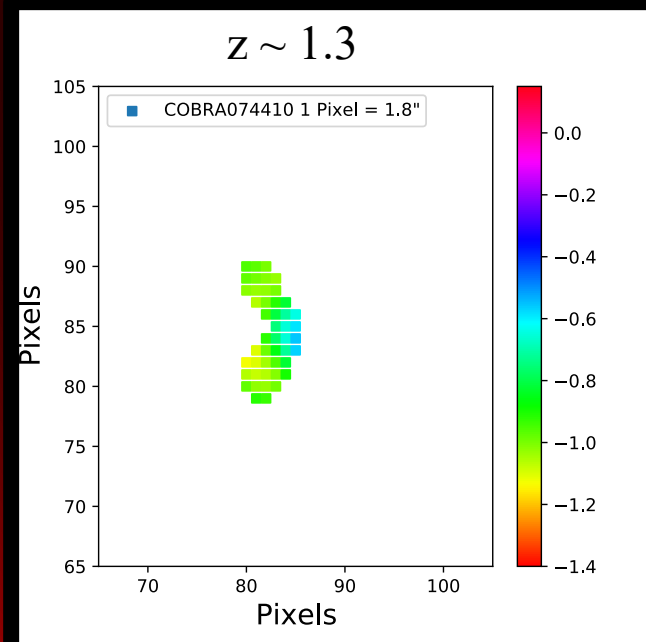
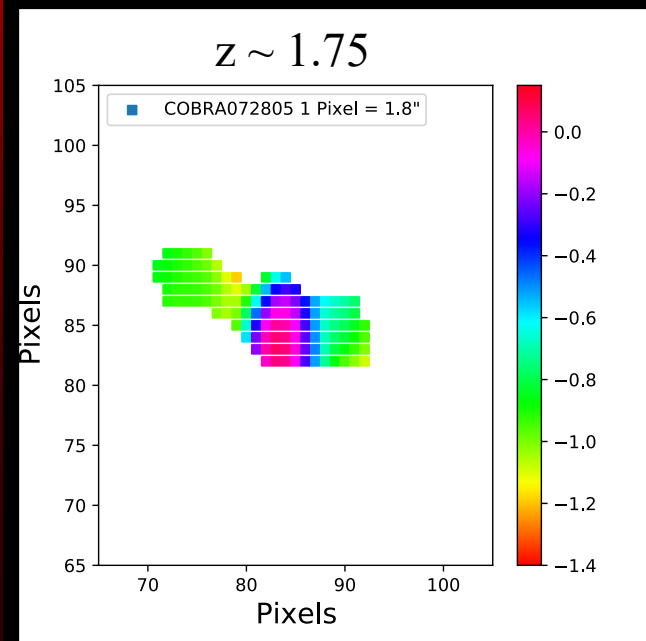
VLASS (3.0GHz)



Golden-Marx et al. (in prep)

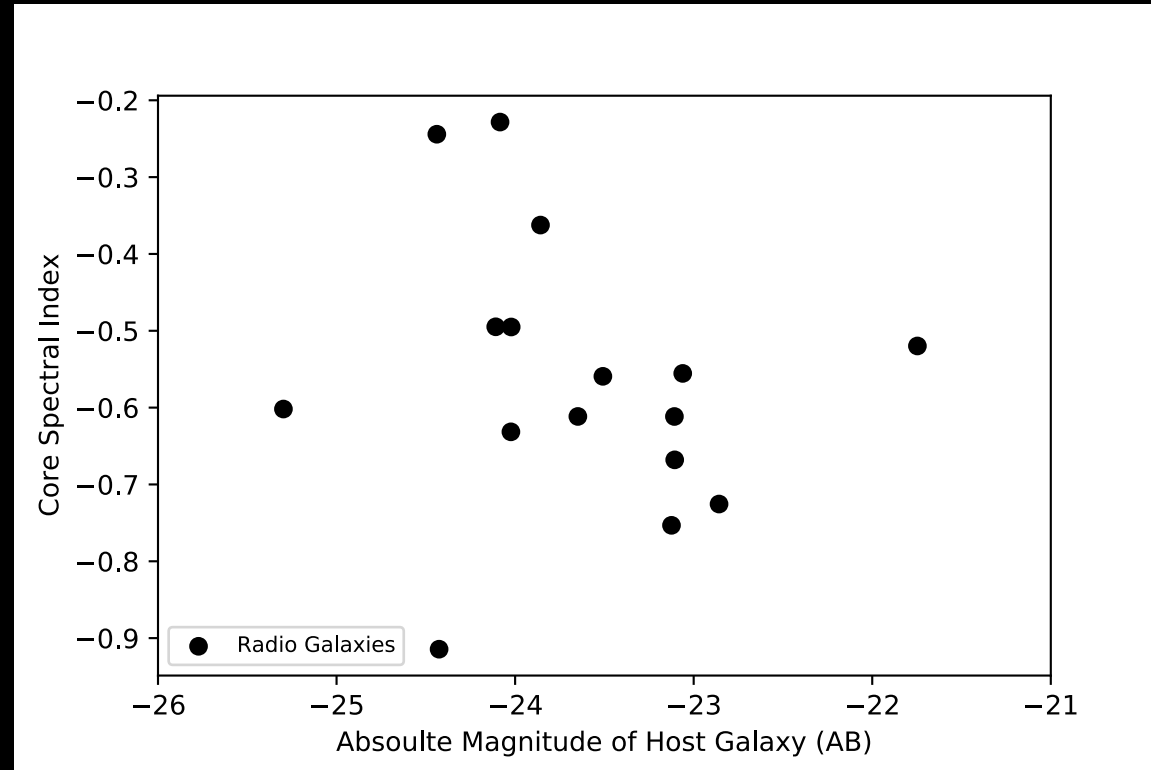
- 21 COBRA red sequence clusters have radio observations in LOFAR
- Aim to characterize the energetics of bent radio sources and trace any lobe asymmetries

Preliminary Spectral Index Maps



Golden-Marx et al. (in prep)

Preliminary Correlations between the Spectral Index and Radio/Host Parameters



Golden-Marx et al. (in prep)

- Brighter host galaxies have radio sources with flatter core spectral indices

Conclusions

- Identify 39 red sequence cluster candidates at $0.35 < z < 2.2$
 - The bent AGN is not necessarily centrally located
- 55% of host galaxies are proto-BCGs
 - In the richest clusters, these proto-BCGs appear to trace overall cluster richness
- Richer clusters on average host narrower bent radio sources
- Identify many potentially outgoing radio sources
 - May indicate these galaxies follow non-radial/circular orbits, or are not disrupted upon falling through the cluster center
- Began the first study of high- z bent radio source spectral indices

